FERMION GENERATIONS FROM THE HIGGS SECTOR

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Abstract

The generation structure in the quark and lepton spectrum is explained as originating from the excitation spectrum S_n of SU(2)$_W$ doublet scalar fields, whose ground state S_1 is the Standard Model Higgs field. There is only one basic family of SU(2)$_W$ doublet left-handed fermions, ν_L, e_L, u_L, d_L, whose bound states with S_n manifest themselves as the generations of left-handed quarks and leptons. Likewise, there is only one basic family of the right-handed fermions, ν_R, e_R, u_R, d_R, which combine with the gauge invariant scalar fields G_n to produce the right-handed quarks and leptons of the second and higher generations. There are only four Yukawa coupling constants, G_ν, G_e, G_u, and G_d and all quark and lepton masses are proportional to them. Suppression of flavor changing neutral currents (GIM mechanism) is automatic. ν_μ and ν_τ are expected to be massive.

I present a theory of the origin of fermion generations in which there is only one fundamental quark/lepton family, while the second and higher ones are a consequence of an excitation spectrum in the scalar sector. The basic family of chiral fermions consists of

$$\ell_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \; q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}, \nu_R, e_R, u_R, d_R$$

with the usual SU(2)$_W \otimes$ U(1)$_Y$ transformation properties. In addition to the fermions, there is a composite bosonic field S whose lowest energy states are the SU(2)$_W$ doublet scalars

$$S_1 = \begin{pmatrix} S_1^+ \\ S_1^0 \end{pmatrix}, \; S_2 = \begin{pmatrix} S_2^+ \\ S_2^0 \end{pmatrix}, \; S_3 = \begin{pmatrix} S_3^+ \\ S_3^0 \end{pmatrix} \ldots$$

We shall assume that there are at least three scalar states below the lowest $J = 1$ state. The ground state S_1 is the familiar Higgs field which develops a vacuum expectation value. S_2, S_3, etc. are its radial excitations labeled by the "generation number." Orthogonality of the states $S_1, S_2, S_3 \ldots$ implies that for $n \geq 2$, S_n has zero vacuum expectation value and zero Yukawa couplings. It also requires that the effective quartic couplings of these states respect the generation number, at least at energies much lower than their mass scale. Under this assumption the effective potential can only be a function of $S_i^\dagger S_i$ and $(S_i^\dagger S_j)(S_j^\dagger S_i)$ and the low energy effective theory possesses a global SU(2) symmetry, the isospin.

Note that this scheme has nothing to do with Technicolor which is a QCD-like theory invented to solve the fine-tuning problem and does not address the fermion generation problem. The S-field envisaged here explains the existence of fermion generations as its radial excitation states. For this purpose it is not necessary to assume QCD-like structure for the S-field – or even that it is based on a new interaction at all.

Gauge invariant scalars

The gauge invariant scalar fields are obtained in the $S_i^\dagger S_j$ (neutral) and $\bar{S}_i^\dagger S_j$ (charged) channels, where $\bar{S} = i\tau_2 S^*$. The fields involving the ground state S_1 are of particular importance, since S_1 is the only Higgs field in the theory (i.e. the field which has negative mass squared in the Lagrangian) and plays a special role in producing the W's, the Z, and the left-handed fermions of the first generation. The only gauge invariant scalar involving only S_1 is $h^0 = \sqrt{2}(S_1^0 - < S_1^0 >)$, the physical Higgs field. For every $n \geq 2$ we have a positive scalar $G_n^+ = \bar{S}_1^\dagger S_n$ and a neutral scalar $G_n^0 = S_1^\dagger S_n$, both of which are labeled by n and thus come in generations. As we shall see, the G_n fields give their generation number to the right-handed fermions and thus are responsible for the generation structure in the right-handed sector.

The quarks and leptons

The left-handed fermions of the n-th generation, $\nu_{nL}, e_{nL}, u_{nL}, d_{nL}$, are composed of the fundamental left-handed fermions ℓ_L and q_L and the n-th generation S field, S_n:

$$\begin{aligned} \nu_{nL} &= \bar{S}_n^\dagger \ell_L \\ e_{nL} &= S_n^\dagger \ell_L \\ u_{nL} &= \bar{S}_n^\dagger q_L \\ d_{nL} &= S_n^\dagger q_L. \end{aligned} \tag{1}$$

The right-handed fermions of the n-th generation are composed of the fundamental right-handed fermions ν_R, e_R, u_R, d_R, and the G_n fields from which they get their generation label:

$$\begin{aligned} \nu_{nR} &= G_n^+ e_R + G_n^0 \nu_R \\ e_{nR} &= G_n^{0*} e_R + G_n^- \nu_R \\ u_{nR} &= G_n^+ d_R + G_n^0 u_R \\ d_{nR} &= G_n^{0*} d_R + G_n^- u_R. \end{aligned} \tag{2}$$

The left- and the right-handed fermions of the first generation meet at the usual Yukawa vertices, Fig. 1(a), while those of the second and higher generations meet at the vertices shown in Fig. 1(b). The four Yukawa coupling constants, G_ν, G_e, G_u, and G_d are the only chiral symmetry breaking parameters in the theory and thus all fermion masses are proportional to them. In the limit in which these coupling constants go to zero all fermions are massless, irrespective of how massive their scalar constituents S_i may be. Note, however, that the quark (lepton) masses of the second and higher generations get contributions from